Nuclear Facilities and Instrumentation

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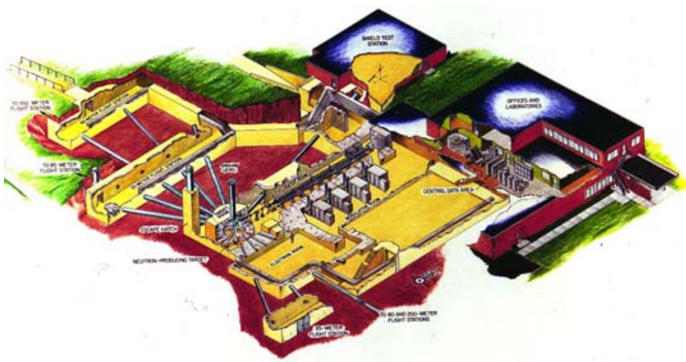
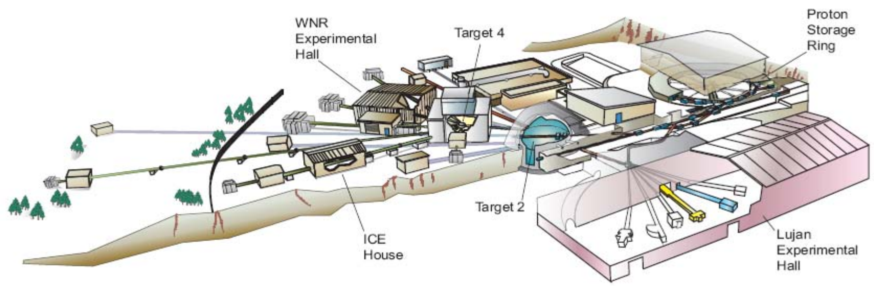
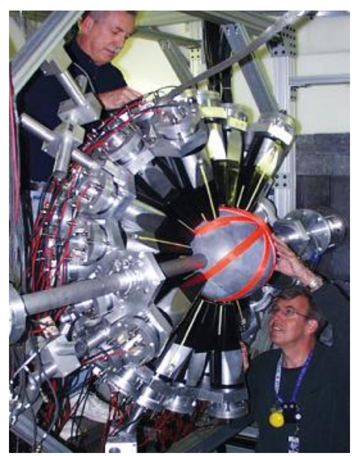






Neutron Facilities
(Charged-particle facilities in W.G. sessions)

- van de Graaff based (Ohio U., TUNL).
  Mostly monoenergetic ($^3H(p,n)$, $^2H(d,n)$, $^7Li(p,n)$).
  E_n ~ 10 keV – 25 MeV.
  Elastic and inelastic scattering, and activation.
- Electron driven (ORELA, RPI).
  White energy spectrum.
  E_n ~ Thermal - 40 MeV.
  (n,γ), (n,f), σ_t, elastic and inelastic scattering, (n,z), $(n,x\gamma)$.
- Proton driven (LANSCE, IPNS, n_TOF).
  White energy spectrum.
  E_n ~ Thermal - 300 MeV.
  (n,γ), (n,f), σ_t, elastic and inelastic scattering, (n,z), $(n,x\gamma)$.

E_n almost always measured using time-of-flight technique.

White Neutron Sources Synopses

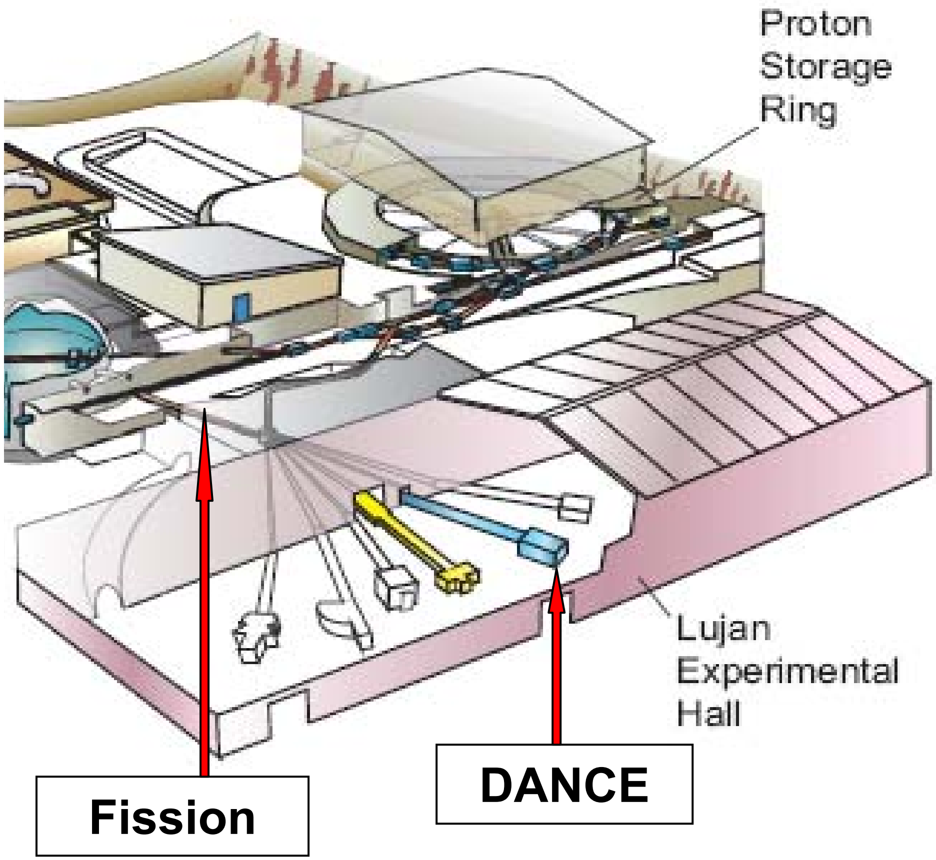
	Facility	E (MeV)	Rate (Hz)	Δt (ns)	NP Instr.	L (m)	$P_{max.}$(kW)
	IPNS	450, p	30	~50	1	20	6.8
	LSDS	800, p	1-100	0.25-125	-	-	0.8
LANSCE	Lujan	800, p	20	125	2	7-50	80
	WNR	800, p	1-100	0.25	5	8-90	3.2
	ORELA	180, e	1-1000	4-30	4	8-200	50
	RPI	60, e	1-500	7-5000	?	?	2.7 (30 ns)
	n_TOF	3000, p	0.278	7	1+1	185.2	6.2

Several facilities are very flexible. Power depends on choice of repetition rate and pulse width. Flux depends on these variables as well as flight path length, filters, and collimation.

Most facilities accommodate simultaneous experiments.

Facility Description: Manuel Lujan, Jr. Neutron Scattering Center (MLNSC or "Lujan") at LANL

- E_p=800 MeV.
- Pulse width = 125 ns.
  625 μs macropulse wrapped 1700 times around PSR and extracted in one turn (360 ns).
- Rep. rate = 20 Hz.
- P_{Max} = 80 kW (100 μA).
- 2 flight paths (for NP).
- L ~ 6-50 m.
- Neutron source:
  W with H_2O moderators (highly moderated).



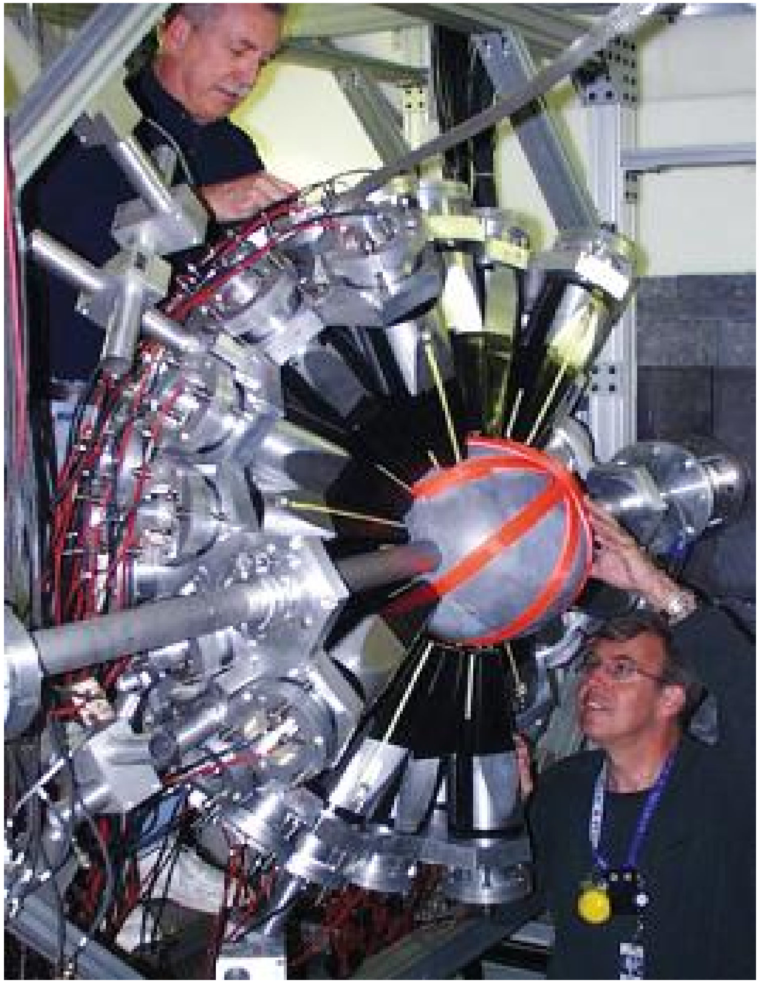
Instrumentation: Lujan

- Device for Advanced Neutron Capture Experiments (DANCE).
  4π BaF_2 with 160 detector elements.

  Transient digitizer (2 per detector) data acquisition system.
  Detailed information for each "event".

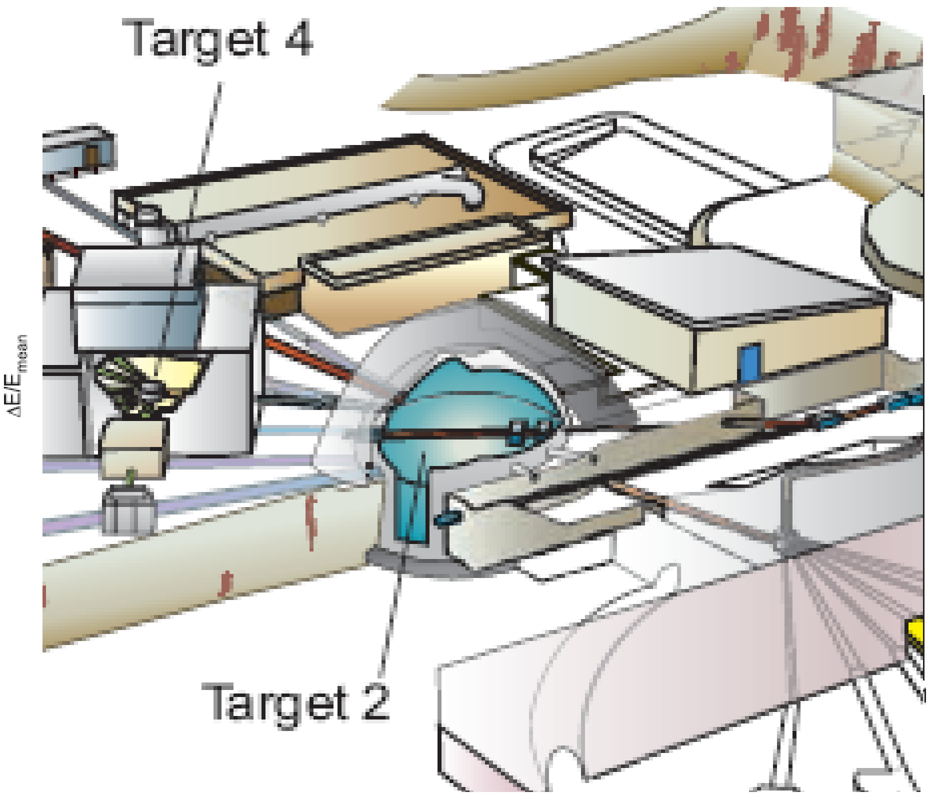
  (n,γ) cross sections for ~mg-sized samples.
  E_n~thermal – 100 keV.

  Fission detectors may be placed inside to measure, e.g., fission-to-capture ratio.



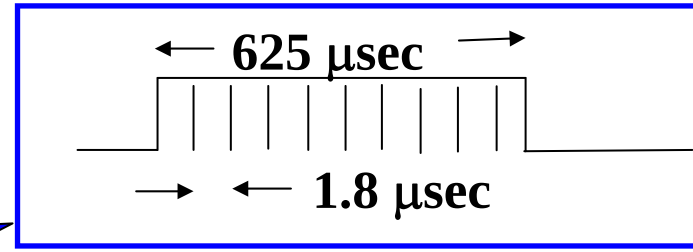
Facility Description: Lead Slowing-Down Spectrometer (LSDS) at LANL

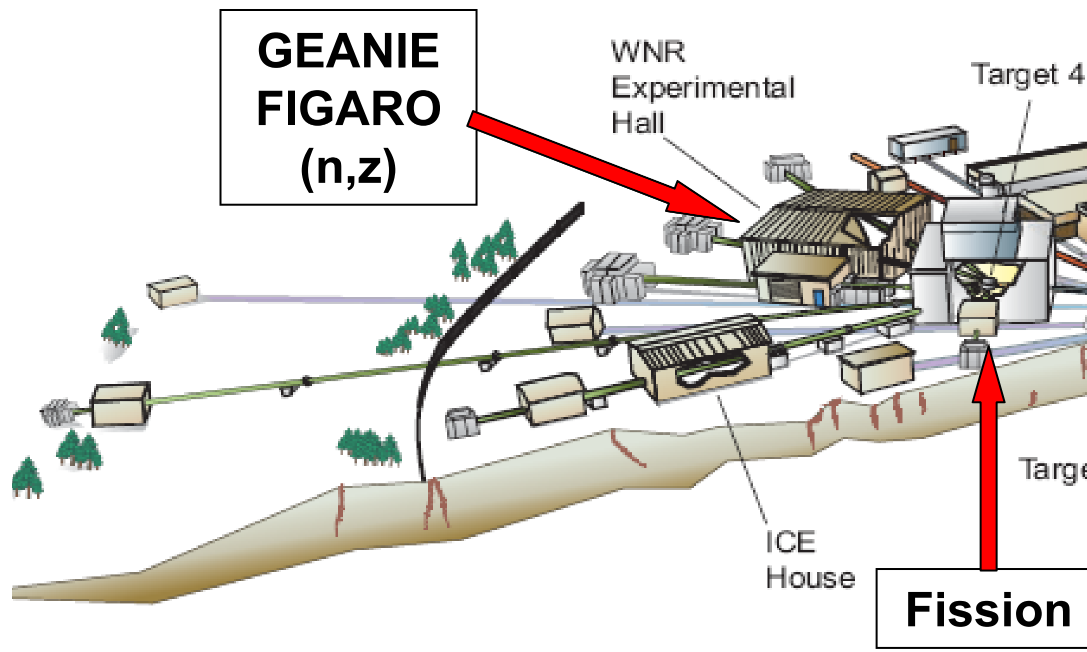
- E_p=800 MeV.
- Resolution ≥ 30%.
- Rep. rate = 1-100 Hz. Fed from linac or PSR.
- P_{Max} = 0.8 kW (1 μA).
- Several "detector stations".
- Neutron source: W surrounded by 1.5-m cube of Pb.
- Solar-cell and ion chamber fission and (n,α) detectors.



Facility Description: Weapons Neutron Research (WNR) at LANL

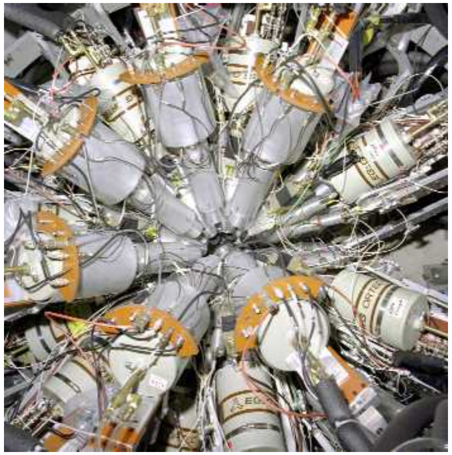
- E_p=800 MeV.
- Pulse width = 0.2 ns.
- Rep. rate:
  1 – 100 Hz (macropulses, 625 μs long).
  > 5 ns micropulse spacing (1.8 μs typ.).
- P_{Max} = 3.2 kW (4 μA).
- 8 flight paths.
- L = 8-90 m.
- Neutron source:
  Water-cooled W, very undermoderated.



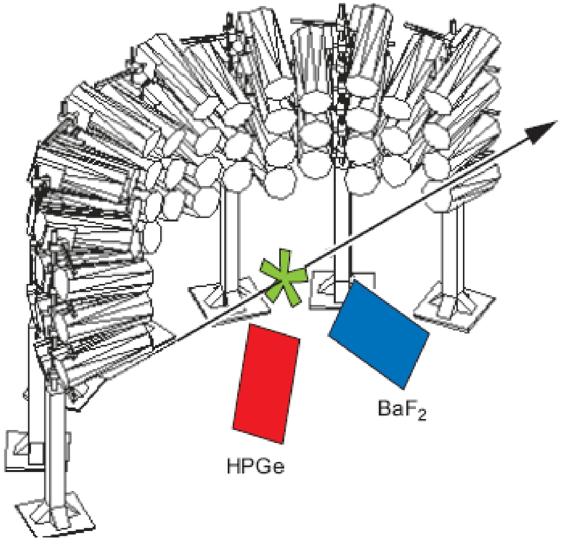


Instrumentation: WNR

- GEANIE (Germanium Array for Neutron-Induced Excitations).
  26 high-resolution γ- and x-ray detectors.
  (n,xn) and (n,n'γ) cross sections from 0.1-200 MeV.

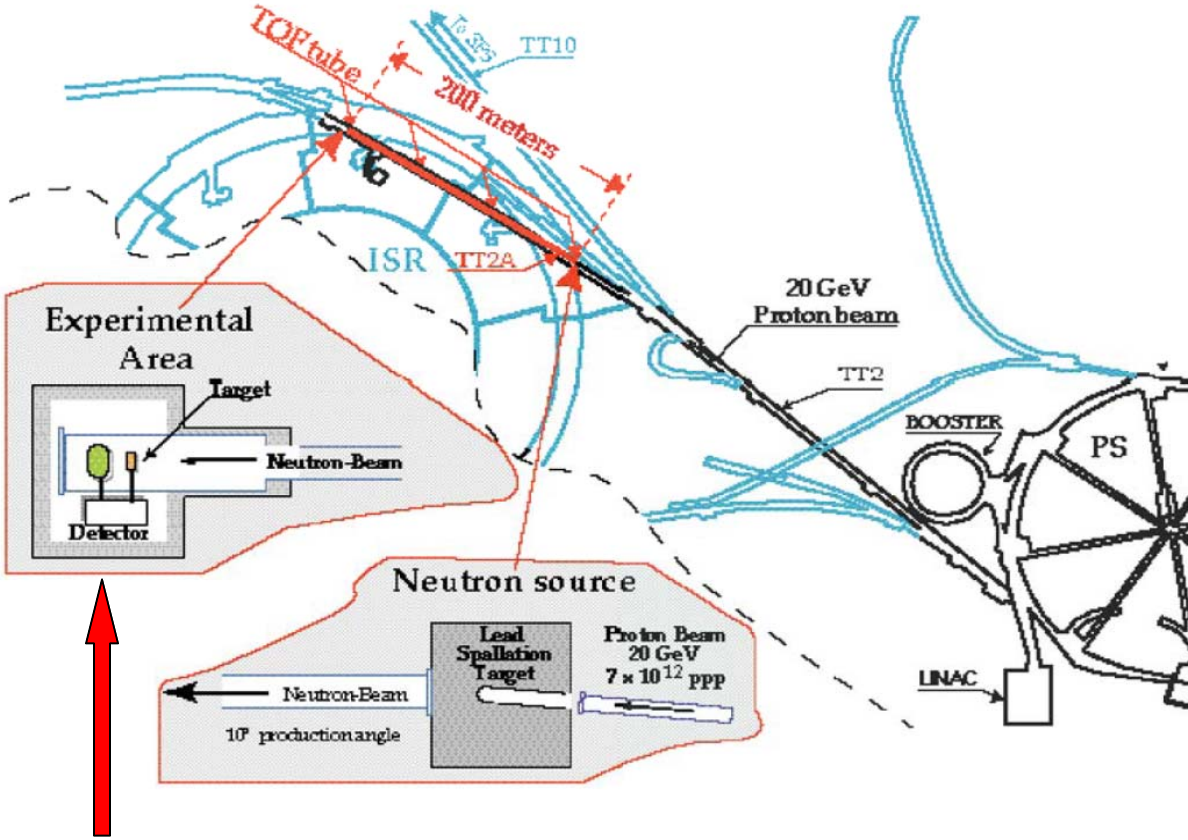


- FIGARO (Fast-Neutron-Induced Gamma-Ray Observer).
  20 neutron detectors plus 2-3 γ-ray detectors.
  Double time of flight.
  Neutron emission spectrum (from fission) as a function of incident-neutron energy.



Facility Description: Neutron Time of Flight (n_TOF) at CERN

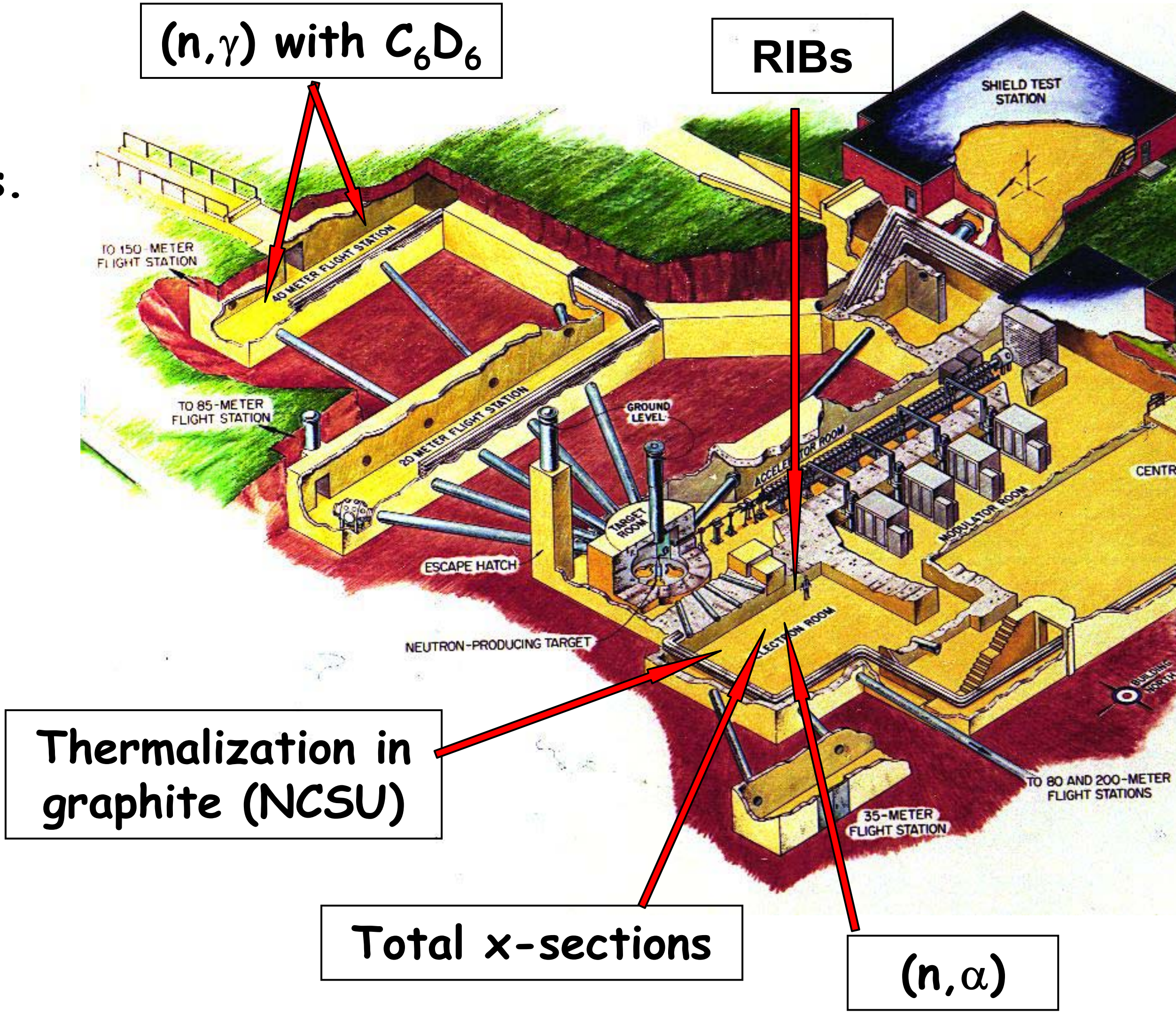
- E_p = 20 GeV.
- Pulse width = 7 ns.
- Rep. rate = 0.069 - 0.278 Hz.
  14.4 s supercycle containing 1 -4 bunches.
- P_{Max} = 6.2 kW.
- 1 flight path.
- 1 detector station.
- L = 185.2 m.
- Neutron source:
  80x80x40 cm³ Pb with 5-cm thick H_2O moderator (very moderated).



4π BaF_2, C_6D_6, or fission detectors.

Facility Description: Oak Ridge Electron Linear Accelerator (ORELA) at ORNL

- $E_e \approx 180$ MeV.
- Pulse width = 4-30 ns.
- Rep. rate = 1-1000 Hz.
- P_{Max} = 50 kW.
- 10 flight paths.
- 18 detector stations.
- L = 8-200 m.
- Neutron source: Ta (optional CH_2 moderator) or Be. Water cooled, undermoderated.

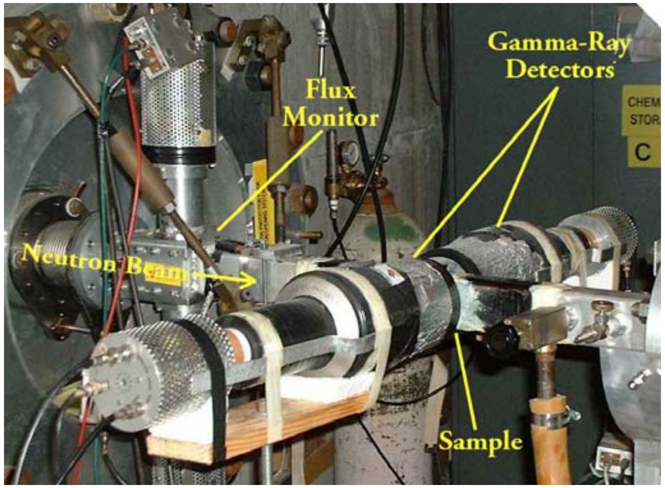


Instrumentation: ORELA

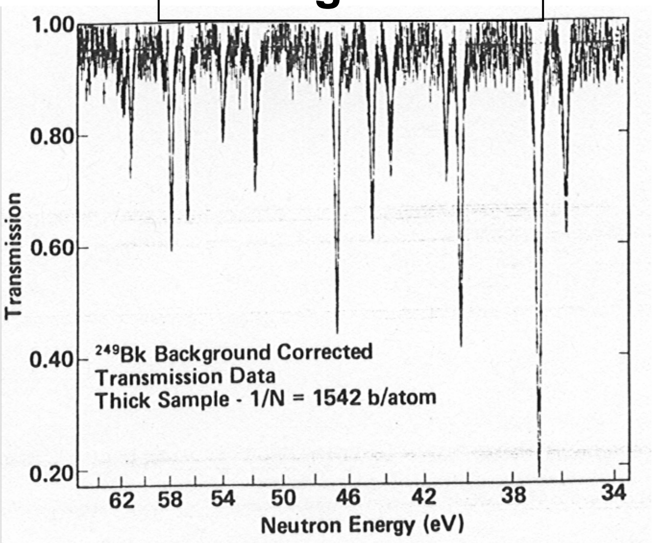
- (n,γ).
  Two setups with 2 C_6D_6 detectors each.
  High resolution, high accuracy data from ~10 eV – 500 keV.
  ~1 g enriched isotope needed.

- Total cross section.
  ^{6}Li-glass and plastic scintillator detectors.
  High resolution, high accuracy data from ~10 Ev – 500 keV.
  Samples as small as a few mg.
  L=18, 80, or 200 m.

- (n,z) and fission setups.
  Compensated ion chambers.



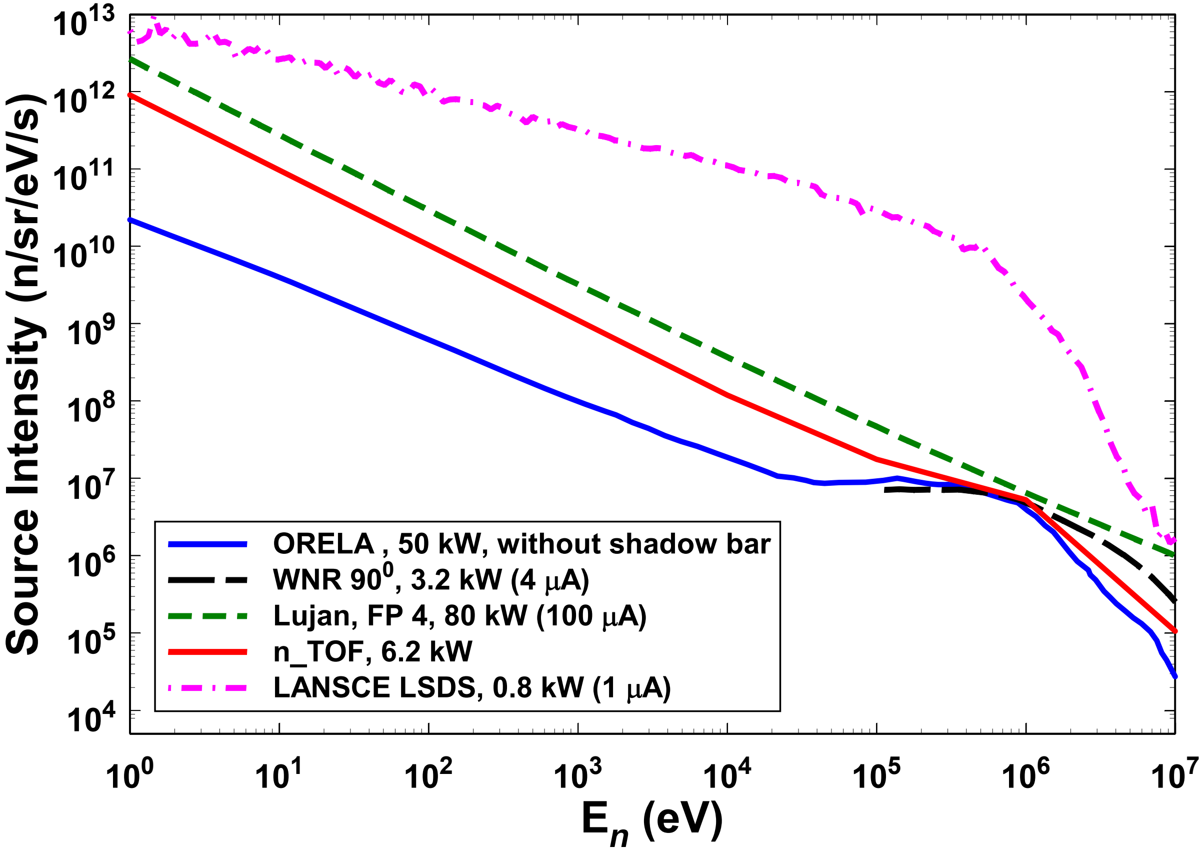
5 mg ^{249}Bk



Comparison of Source Intensities

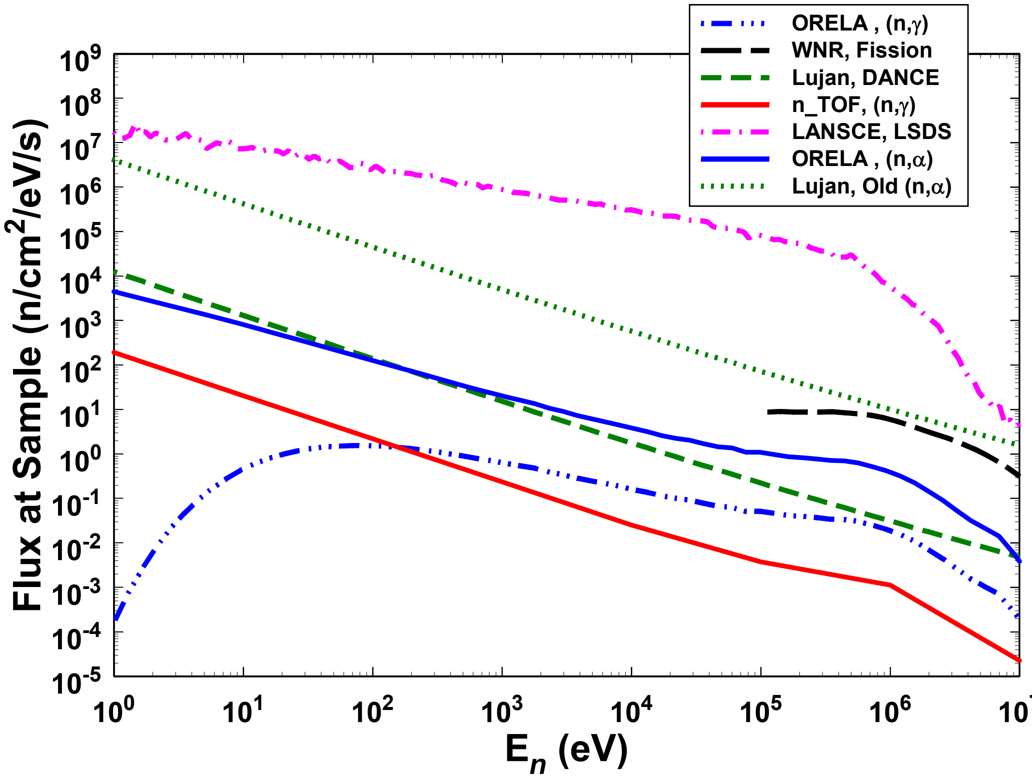
- Maximum source intensities of current facilities. Illustrates potential flux attainable if there are no other limitations.

- Things that limit useful flux.
  Background.
  Resolution.
  Collimation.
  Frame overlap.



Comparison of Fluxes at Actual Experiments

- LSDS – P=0.8 kW.
- Lujan, Old (n,α) – L=7 m, P=80 kW, 80% of flux-trap moderator viewed.
- Lujan, DANCE – L=20 m, P=80 kW, collimator restricts view of wing moderator.
- n_TOF – L=185.2 m, P=6.2 kW, collimator restricts view.
- ORELA (n,γ) – L=40 m, P=8 kW, Δt=8 ns, ^{10}B filter, 525 Hz.
- ORELA (n,α) – L=8.84 m, P=8 kW, Δt=8 ns, Cd filter, 525 Hz.
- WNR Fission – L=9 m, P=3.2 kW (4 μA), 90^0.



Resolution

- **Inherent facility resolution has two main components:**

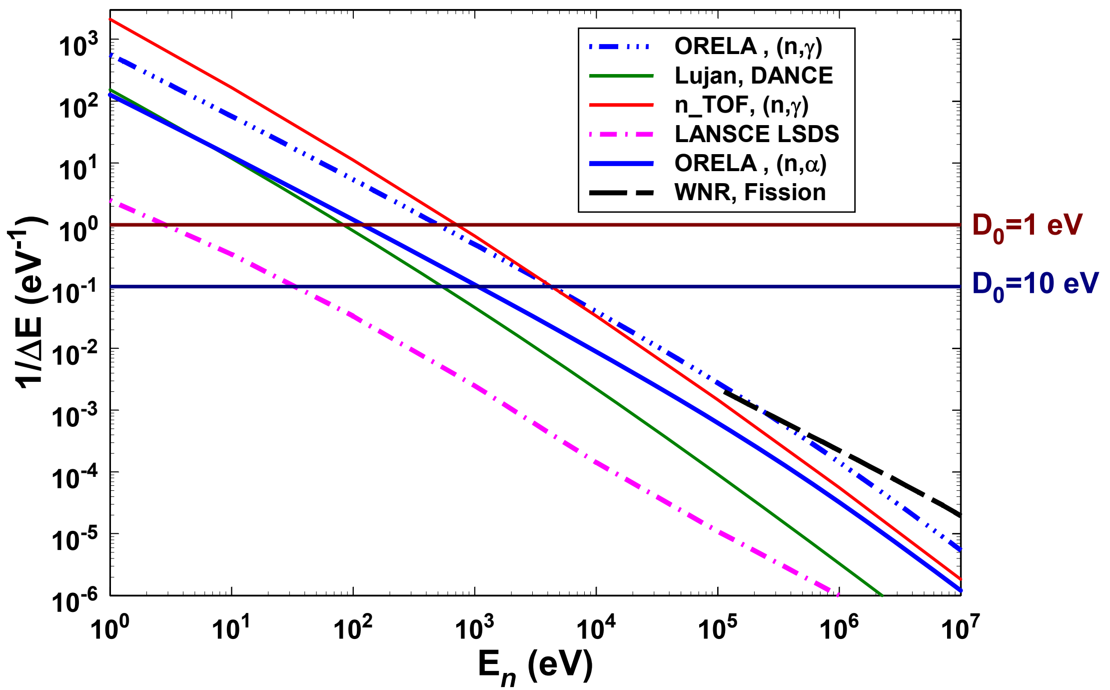
  Δt, width of electron or proton beam striking target.

  ΔL, flight path length uncertainty.
  Uncertainty of where neutrons were "born".
  Large moderators (e.g., Lujan and n_TOF) result in sizeable low-energy tails due to this component.
  I used FWTM criterion of Coceva *et al*. for ΔL.

$$\Delta E = 2E\sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta t}{72.3L}\right)^2 E}$$

Comparison of Resolutions for Actual Experiments

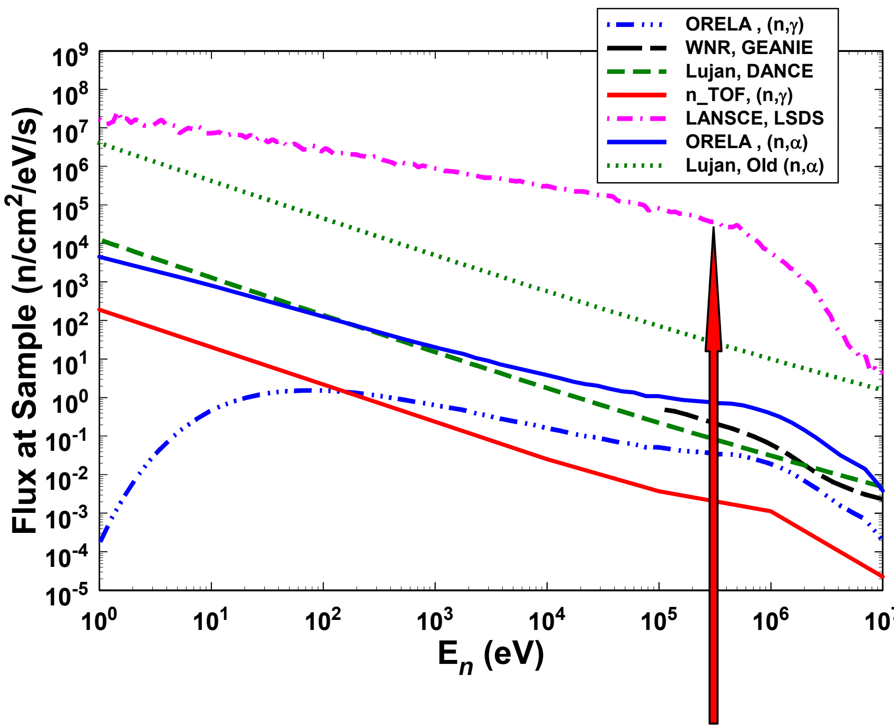
- I used $1/\Delta E$ so that "bigger is better".
- Same conditions as flux plot two slides ago.
- ORELA and n_TOF ΔL from Coceva et al.
- Lujan, DANCE ΔL from my SAMMY fits.
  Lujan $(n,\alpha) \approx$ 3x worse than DANCE.
- Assumed ΔL=2 cm for WNR.
  3 cm dia. by 7.5 cm long target viewed at 90^0 angle.

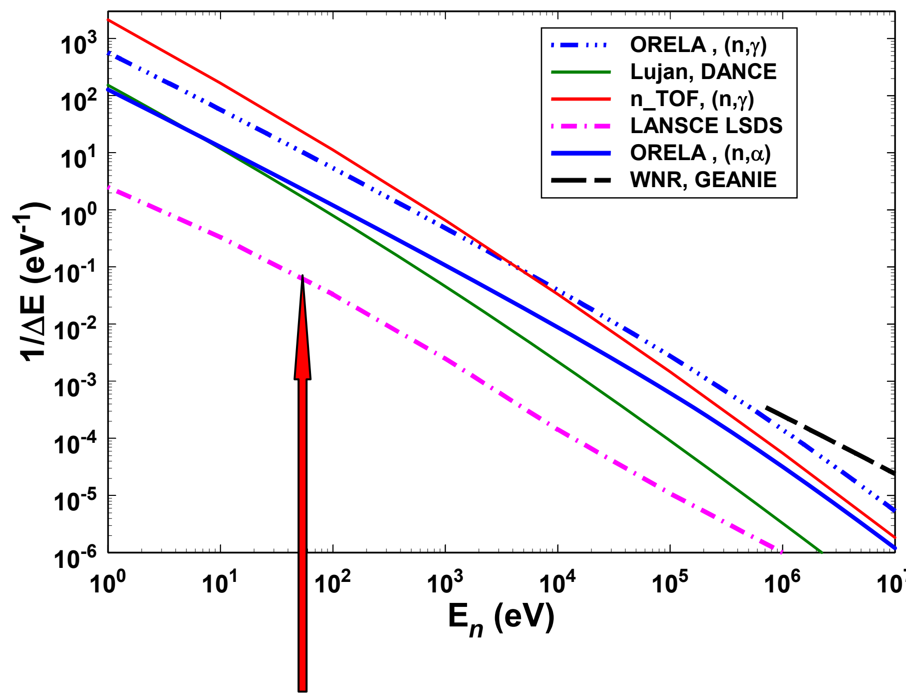


$D_0 \approx 1$ eV for ^{241}Pu, 10 eV for ^{240}Pu

Moore's Law Can Be a Useful Starting Point
for deciding which facility to use for a particular measurement

- You can either learn: Less and less about more and more
  or
  More and more about less and less.



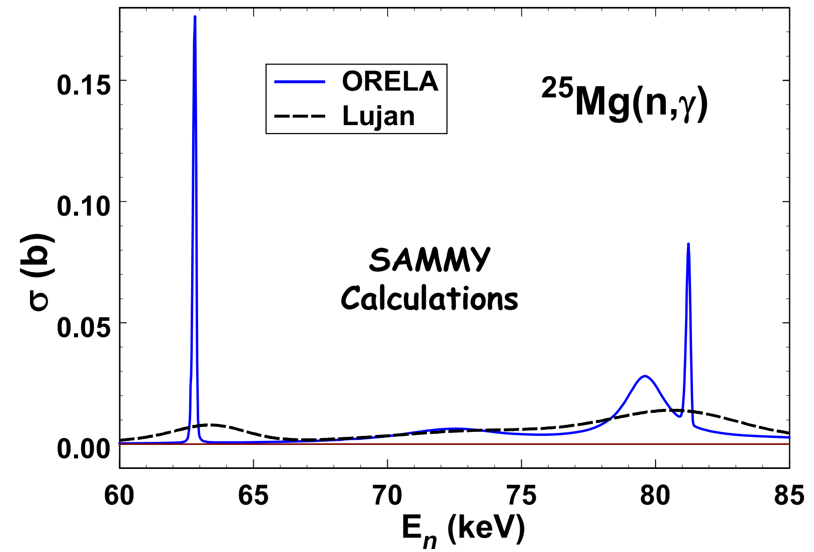


Facility with highest flux has lowest resolution and vice versa

Why Resolution Can Be Important, #1

Improves S/N ratio.

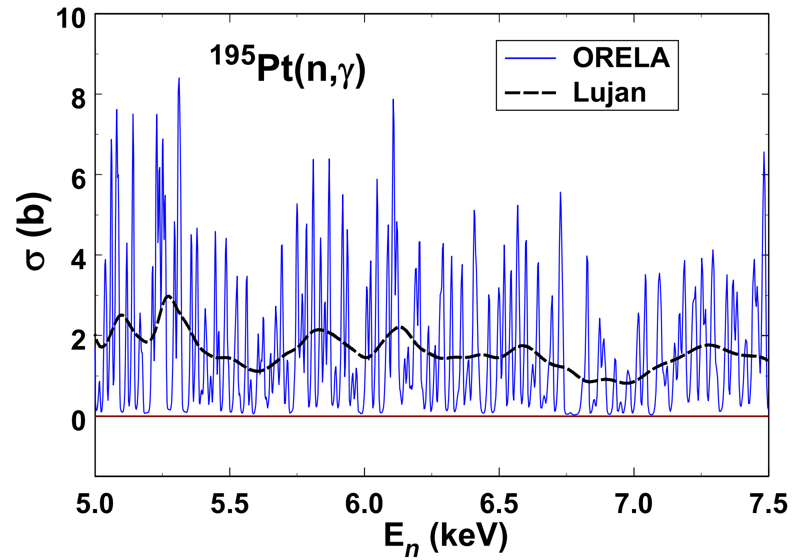
Makes it possible to measure small, resonance-dominated cross sections (e.g., (n,γ) on lighter nuclides and near closed shells).



Provides more information for applications (self-shielding corrections) and for improving nuclear models.

Determine strength functions and level densities more accurately and over a wider range.

Models always will be needed to predict what can't be measured.



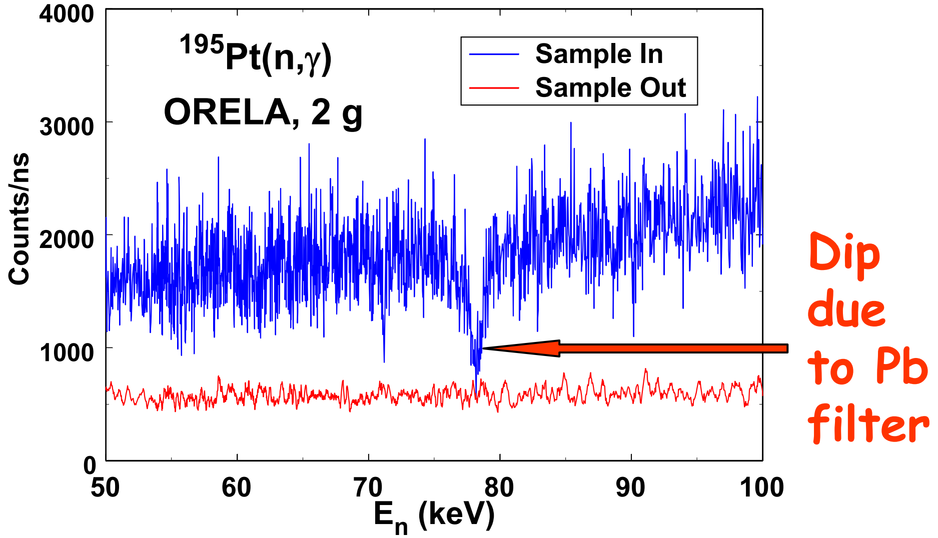
Why Resolution Can Be Important, #2

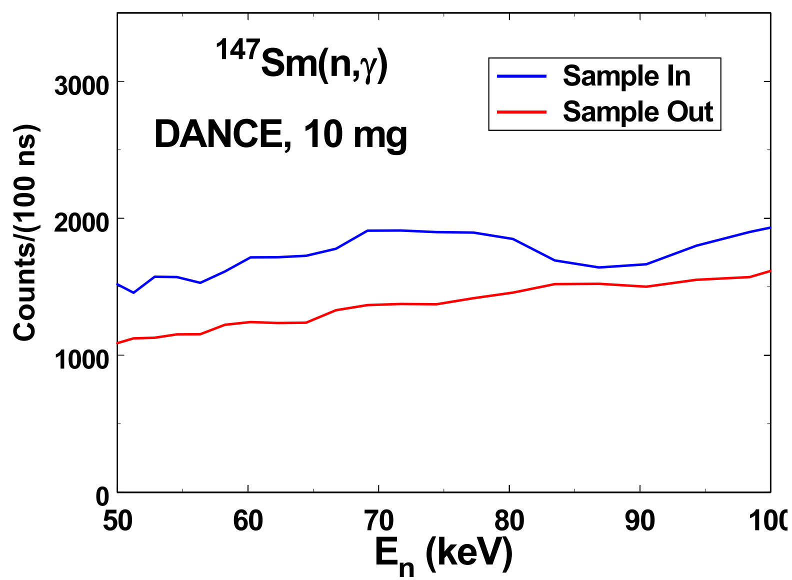
- Higher Accuracy in Unresolved Region.

  Resolved region extends to higher energies (allows better background determination).

  Black filters can be used to higher energies to evaluated backgrounds and reduce systematic uncertainties (filter dips smeared out too much if resolution too poor).

Measurements





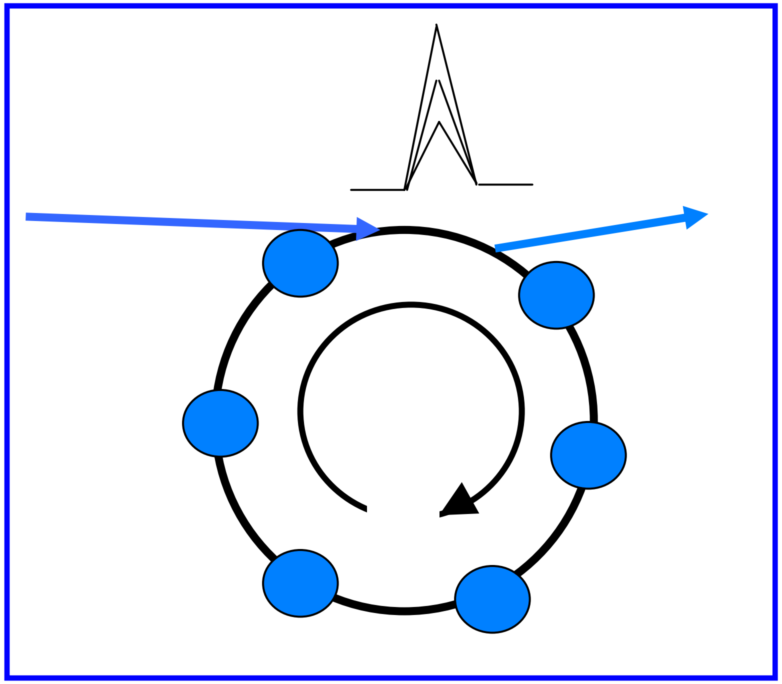
Facility Strengths

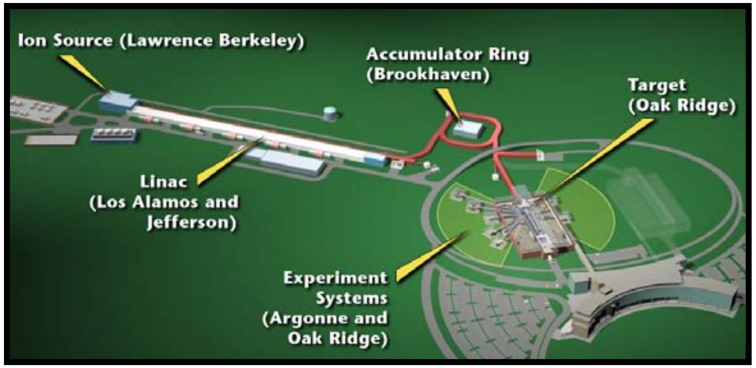
- **LSDS.**
  (n,f) and (n,α) on very small (~10 ng) samples E_n~thermal – 10 keV.
- **Lujan.**
  (n,γ) and (n,f) on small (~1 mg) samples E_n~thermal – 100 keV.
- **ORELA.**
  High resolution and high accuracy (n,γ), σ_t, (n,α), (n,f) on ~1 g samples for E_n~1 eV – 1 MeV. σ_t on few mg samples.
- **WNR.**
  High resolution (n,f), (n,xγ), (n,z), and other data on ~1 g samples for E_n~100 keV – 300 MeV.

Possible Future Facility Improvements

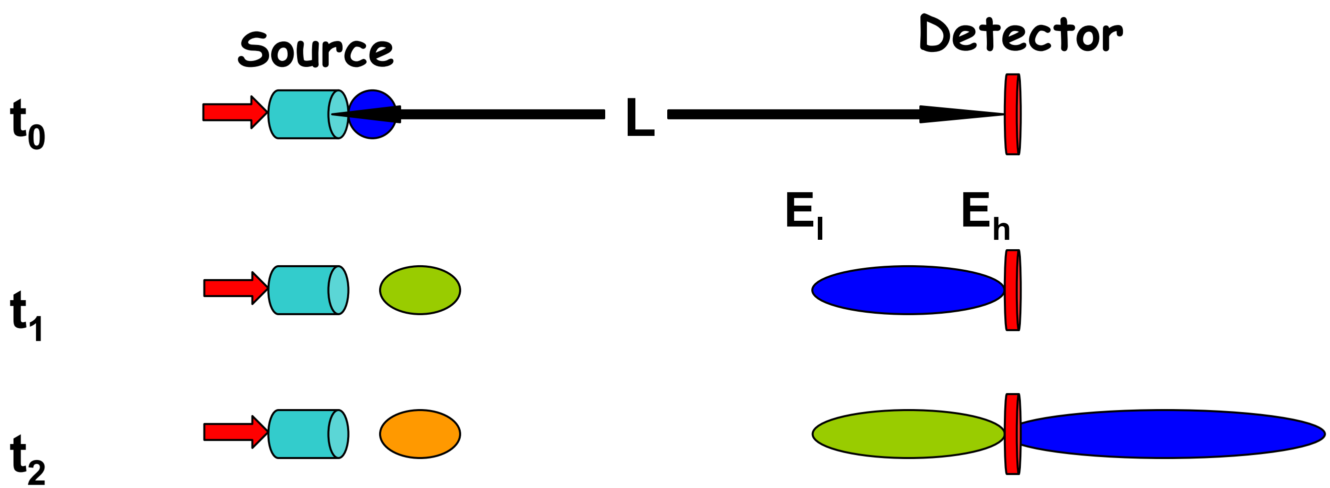
- LANSCE "superpulses".
  Use PSR to stack micropulses and extract at longer spacing. Send to new target at WNR (optimized for lower E).
  Extends energy range before overlap (to ~1 keV) and increases flux (current ~2-12x higher).
  Both high flux and good resolution.

- Beam line at SNS.
  ~20x higher flux than Lujan at 3x worse resolution.
  More radioactive samples accessible.





Frame Overlap (Wraparound)



- Need $\Delta t = t_1 - t_0$ large enough so that highest-energy neutrons from one pulse don't run into lowest energy neutrons from previous pulse before detector position: $\Delta t > 72.3*L*(E_l^{-1/2} - E_h^{-1/2})$.
- Can "cure" by increasing pulse spacing (decreases ϕ at all E), using filters to absorb low-energy neutrons (decreases ϕ at low E), by decreasing L (worsens resolution), by detector thresholds (in some cases), or by correcting via additional measurements (if low-energy flux not too large).